BULLETIN

OF THE INSTITUTE OF METALS

VOLUME 4 APRIL 1958 PART 8

INSTITUTE NEWS

Award of Institute Medals

The Council has resolved to make the following awards of medals, which will be presented by the President at the Annual General Meeting at Church House, Great Smith Street, Westminster, S.W.1, on the morning of Tuesday, 29 April:

(a) *The Institute of Metals (Platinum) Medal* for 1958 to Professor-Emeritus ROBERT SALMON HUTTON, M.A., D.Sc., in recognition of his services to non-ferrous metallurgy.

(b) *The Rosenhain Medal* for 1958 to Dr. JOHN HERBERT HOLLOMON, Manager of the Metallurgy and Ceramics Research Department, General Electric Co., Schenectady, N.Y., in recognition of his outstanding contributions to knowledge in the field of physical metallurgy.

No award will be made of the W. H. A. Robertson Medal and Premium for 1957.

Election of Members

The following 9 Ordinary Members, 2 Junior Members, and 9 Student Members were elected on 21 February 1958:

As Ordinary Members

DRYSDALE, Royston Fraser, A.I.M., Technical Director, The Walterisation Co., Ltd., Research and Development Laboratories, The Knoll, Holmwood, Dorking, Surrey.

HENDERSHOT, Harold Frederick, Works Technical Director, Huntington Works, International Nickel Co., Inc., Huntington, W.Va., U.S.A.

KOZLIK, Roland Arthur, M.S., Supervisor, Non-Ferrous Section, Research Laboratory, International Nickel Co., Inc., 30 Oak Street, Bayonne, N.J., U.S.A.

RYCHNER, Reinhard, Dipl.Ing., Directeur Technique, L'Aluminium Belge S.A., 100 Avenue Henri Borguet, Chênée-lez-Liège, Belgium.

SILVERTSEN, John M., M.S., Ph.D., Assistant Professor of Physical Metallurgy, Institute of Technology, University of Minnesota, Minneapolis 14, Minn., U.S.A.

THOMAS, Angus Arnold, M.A., A.M.I.Mech.E., Engineering Sales Manager, Davy and United Engineering Co., Ltd., Park Iron Works, Sheffield 4.

WALKER, Peter Noel, Quality Controller and Metallurgist, Wednesbury Tube Co., Ltd., Bilston, Staffs.

WILMS, Geoffrey Russell, B.Met.E., M.Eng.Sc., Ph.D., Senior Scientific Officer, High-Temperature Alloys Group, Defence Standards Laboratories, Ascot Vale, Vic., Australia.

WRIGHT, William John, B.Sc., Chief Chemist, Noranda Copper and Brass, Ltd., Durocher and Sherbrooke Street East, Montreal East, P.Q., Canada.

As Junior Members

BAINBRIDGE, John Evelyn, Assistant Experimental Officer (Metallurgy), Atomic Energy Research Establishment, Harwell, Berks.

MORETON, Brian Berkeley, B.Sc., Research Metallurgist, The Steel Company of Wales, Ltd., Department of Industrial Metallurgy, University of Birmingham.

As Student Members

ANDREWS, Henry Le Roy, B.Met.E., Graduate Student, University of Michigan, Ann Arbor, Mich., U.S.A.

ASTLEY, Ian, Undergraduate, Department of Metallurgy, University of Cambridge.

BELL, John, Student, 161 Fernhill Road, Bootle 20, Lancs.

BETTS, Bryan Peter, Undergraduate, Department of Metallurgy, University of Birmingham.

DAY, Joseph James, L.I.M., Research Assistant, Fulmer Research Institute, Stoke Poges, Bucks.

HILL, Ernest John Harold, Laboratory Assistant, Nelson Research Laboratories, The English Electric Co., Ltd., Stafford.

SMITH, David, Student, 2, Johnston Street, Workington, Cumberland.

TURNER, William Robert Alan, Experimental Assistant, Wolverhampton and Staffordshire College of Technology, Wolverhampton, Staffs.

WINSLOW, Fitz Randolph, B.S.Met.Eng., Graduate Student, Carnegie Institute of Technology, Pittsburgh 13, Pa., U.S.A.

PERSONAL NOTES

DR. M. BALICKI is now a consulting metallurgist at 402E, 74th Street, New York 21, N.Y.

MR. W. M. BEASLEY has left Metals and Controls Corp. to become Professor in the Engineering Experimental Station of the University of New Hampshire, Denham, N.H.

MR. Y. L. CHICHMANIAN has left Egypt and is now with Western Copper Mills, Ltd., Vancouver, B.C.

DR. A. H. COTTRELL, recently delivered the 1958 Institute of Metals Division lecture to the A.I.M.E. His subject was " The Theory of Brittle Fracture in Metals ".

MR. G. H. EDMUNDS has left the American Brake Shoe Co., and is now with the Bell Telephone Laboratories, Inc., Allentown, Pa.

MR. L. H. FAIRBANK has left Henry Wiggin and Co., Ltd., and joined the Research Department of Birlec, Ltd., Birmingham.

Mr. D. W. Hall of Rolls-Royce, Ltd., Barnoldswick, wishes it to be known that he is not the Mr. Douglas Hall who has recently been appointed General Works Manager of Low Moor Alloy Steelworks, Ltd., Bradford.

Mr. M. M. Hallett has been elected Chairman of the Technical Council of the Institute of British Foundrymen.

Dr. W. R. Hibbard, Jr., has been elected President of the Metallurgical Society of the A.I.M.E.

Mr. M. I. Jacobson has left Ohio State University and joined the Research and Development Department of the Chase Brass and Copper Co., Inc., Waterbury, Conn.

Dr. B. R. Nijhawan, Director of the National Metallurgical Laboratory, Jamshedpur, has been awarded the " Padma Shri " by the President of the Republic of India in recognition of his distinguished services to science in India.

Mr. R. Oliver has been appointed Chief of Metals Development Department, Osram Lamp Works, Wembley. [This amends the note in the December *Bulletin* (p. 23)].

Dr. H. M. Otte (not Dr. H. M. Otto as stated in the December *Bulletin*) has taken up an appointment with RIAS Inc., Baltimore, Md.

Mr. P. G. Partridge, having completed his National Service, is now engaged at the Cavendish Laboratory, Cambridge.

Professor A. Portevin has been elected Vice-President of the Académie des Sciences for 1958.

Mr. R. R. Ross has left the Kaiser Aluminum and Chemical Corp. and joined the Aluminum Division of the Olin Mathieson Chemical Corp., Hannibal, Ohio.

Dr. D. B. Scott has left Revere Copper and Brass, Inc., and is now with the Atomic Power Division of Westinghouse Electric Corp., Pittsburgh, Pa.

Dr. P. P. G. L. Siriwardene has been appointed a director of the Government-sponsored Ceylon Mineral Sand Corporation. He will continue to hold his appointment at the University of Ceylon.

Dr. T. J. Whalen has left the Pennsylvania State University to become a Research Engineer with the Ford Motor Co., Dearborn, Mich.

Mr. D. R. Wood is now a member of the Development Staff of the Mond Nickel Co., Ltd., Birmingham.

Dr. O. H. Wyatt has left the Engineering Department, Cambridge, and is now with the Hawker Siddeley Nuclear Power Co., Ltd., Langley, Bucks.

NEW OFFICERS

Below are given some biographical details of members who take office as President, Vice-Presidents, and Ordinary Members of Council at the Annual General Meeting on 29 April.

Marshal of the Royal Air Force, The Lord Tedder

(President)

Arthur William Tedder, son of the late Sir Arthur John Tedder, was born in 1890 at Glenguin, Stirlingshire. After being educated at Whitgift School, Croydon, and Magdalene College, Cambridge, he entered the Colonial Service. At the outbreak of war in 1914 he returned to England to join the Army, being commissioned in the Dorsetshire Regiment. Subsequently he was seconded to the Royal Flying Corps, with which he served in France and Egypt.

On the creation of the Royal Air Force, Lord Tedder was commissioned in that Service and quickly gained promotion. At the outbreak of the Second World War, he was Director-General of Research and Development, Air Ministry. In 1941 he was appointed Air Officer Commanding in Chief, R.A.F., Middle East, and in 1943 he became Deputy to General Eisenhower at Supreme Headquarters, Allied Expeditionary Force. At Berlin on 7 May 1945, Lord Tedder signed the ratified document of unconditional surrender terms on behalf of the United Kingdom. At the end of the War in Europe,

he was created first Baron Tedder of Glenguin, and in 1946 succeeded Lord Portal of Hungerford as Chief of the Air Staff.

Since his retirement from the Service, Lord Tedder has continued to devote much time to the activities of the R.A.F. and to the welfare of those who serve in it, and in 1953 he was elected president of the Royal Air Force Association. In 1950 he joined the Board of the Distillers Co., Ltd., and in 1954 he was appointed Chairman of the Standard Motor Co., Ltd. He has also taken part in many national and business activities, including serving a term as a Governor of the B.B.C. He has been Chancellor of Cambridge University since 1950.

Lord Tedder holds many British and foreign decorations and has received honorary degrees from a number of universities. He was awarded the C.B. in 1937 and created K.C.B. and G.C.B. in 1942.

Mr. G. L. Bailey

(Vice-President)

George Leo Bailey was educated at King Edward VI Grammar School, Five Ways, Birmingham, and at Birmingham University, where he graduated in metallurgy in 1921. He held a Bowen Research Scholarship in the Metallurgy Department at Birmingham in the year 1921–22 and was awarded the degree of M.Sc. in 1922 for his post-graduate research.

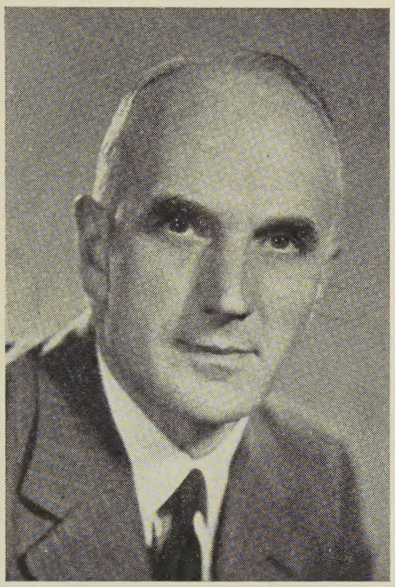
In 1922 he joined the staff of the Metallurgical Branch of the Research Department, Woolwich, where he remained until 1930, when he took up a post with the British Non-Ferrous Metals Research Association. He has served with the Association first as Chief Officer of the Development Department, later as Deputy Director, and since November 1944 as Director.

Mr. Bailey's main research work has been in the field of

the casting of metals and alloys, particularly in the casting of brass ingots, and he was the joint author with Dr. R. Genders of a monograph on this subject. He has contributed a number of papers to the *Journal* of the Institute of Metals.

He has served on various metallurgical committees of the Ministry of Supply and the Admiralty, on the Inter-Service Metallurgical Research Council, and on the Non-Ferrous Metals Committee of that Council.

Mr. Bailey was elected a member of the Institute of Metals



in 1921 and served as an Ordinary Member of Council from 1940 to 1944, as a Vice-President from 1944 to 1947, as representative of the Institution of Metallurgists at meetings of the Council from 1947 to 1949, and again served as an Ordinary Member of Council in 1950–52 and 1956–58 and Vice-President 1952–55.

He was a Founder Member of the Institution of Metallurgists, Honorary Treasurer from 1951 to 1955, and President for the year 1956–57. Mr. Bailey was awarded the C.B.E. in the New Year Honours of 1952.

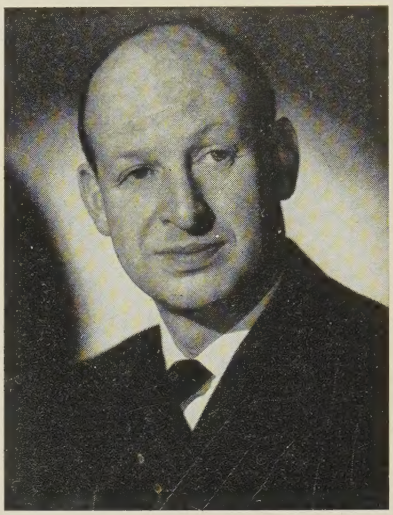
Mr. R. D. Hamer

(Vice-President)

Robert Dennis Hamer was born in 1913 in London and educated at the University of Saskatchewan, Canada, where he obtained the degree of Bachelor of Science in 1933, and at the Charlottenburg Technische Hochschule in Berlin, Germany. After a period of research experience in both the steel and aluminium industries in Germany, he returned to Canada in 1936 and joined the Aluminum Company of Canada at Arvida. Subsequently, he served in several plants and departments of Alcan until, after the outbreak of war, he "flew a desk" between Montreal, Ottawa, and Washington, keeping materials and equipment flowing to the great hydro-electric and aluminium projects then undertaken in Canada.

In 1945 he transferred to Aluminium Laboratories Limited, Montreal, the technical management organization of the Aluminium Limited Group of Companies. Five years later he came to Europe as a Vice-President and Director with responsibility for the company's research and development affairs in Europe, Africa, and India, a position which has kept him travelling to maintain liaison with the company's many foreign factories and with other scientific metallurgical bodies. He is also a Director of the Magnesium Company of Canada Limited, Montreal.

Mr. Hamer's two main interests are the more effective use of fundamental research by the aluminium industry and the development of continuous automatically controlled fabricating processes.

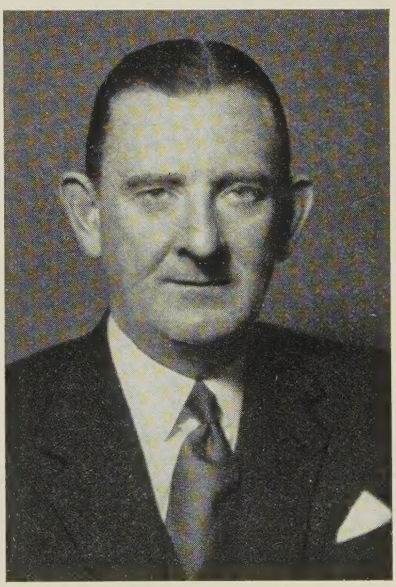


Mr. Hamer is a Fellow of the Institution of Metallurgists and of The Royal Institute of Chemistry. He was President of the Aluminium Development Association in 1953, and is a member of Council of the British Non-Ferrous Metals Research Association. He became a member of the Institute Council in 1954 and is currently Chairman of the Finance and General Purposes Committee.

Sir Ronald Prain

(Vice-President)

Ronald Lindsay Prain was born at Iquiqui, Chile, in 1907, and educated at Cheltenham College.



In 1926 he joined The Anglo Metal Co., Ltd., of which he was made a Director in 1936 and Chairman in 1946. In 1939 he joined the Board of Rhodesian Selection Trust, Ltd., in 1943 he became Managing Director of Roan Antelope Copper

Mines, Ltd., and Mufulira Copper Mines, Ltd., and in 1950 he became Chairman of these three Companies. During this period he also joined the Boards of Selection Trust, Ltd. (1944), San Francisco Mines of Mexico, Ltd., (1946), and others.

Sir Ronald was Controller of Diamond Die and Tool Control, Ministry of Supply, 1940–45, and of Quartz Crystal Control, Ministry of Supply, 1943–45. He is a Director of The International Nickel Company of Canada, Ltd. (1951), and a Member of the Advisory Committee of that Company and of The Mond Nickel Co., Ltd. He is Chairman of the Merchant Bank of Central Africa (1956) and is a Director of Barclays Bank D.C.O. (Rhodesian Local Board) (1953) and Wankie Colliery Co., Ltd. (1953).

In 1953, when Roan Antelope Copper Mines, Ltd., Mufulira Copper Mines, Ltd., Rhodesian Selection Trust, Ltd., and other associated Companies moved their Head Offices to Rhodesia, he continued as Chairman, and is now Chairman and President of these and other Companies in what is now known as the Rhodesian Selection Trust Group of Companies.

He has been Chairman of the Management Committee of the Copper Development Association since 1949 and Chairman of Council of the Association since 1951. He is also a Member of Council of the British Bureau of Non-Ferrous Metal Statistics, British Non-Ferrous Metals Research Association (Vice-President), British Overseas Mining Association (President 1952), and The Royal African Society (Vice-President). In addition, he is a Member of Council of Cheltenham College.

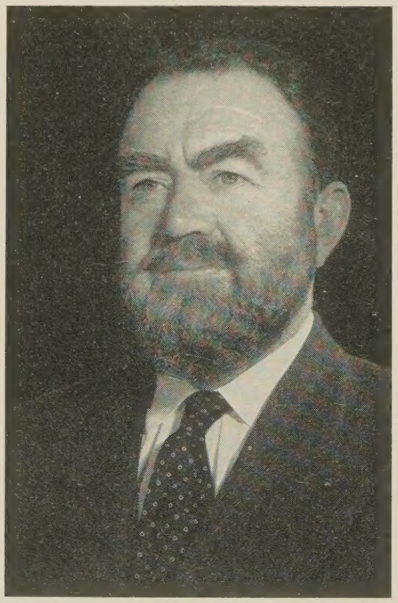
Sir Ronald was awarded the O.B.E. in 1946 and knighted in 1956. He was recently made an Honorary Member of the Institution of Mining and Metallurgy.

The Hon. Geoffrey Cunliffe

(Member of Council)

Geoffrey Cunliffe was born at Headley, Surrey, in 1903. He was educated at Eton and Cambridge.

His first interest in the metal industries was in the 1920s,



when he was a Director of the Arizona Molybdenum Company, and interested in prospecting activities in Northern Mexico.

He joined The British Aluminium Co., Ltd., in 1932. He became a Director of the Company in 1938, and at the outbreak of war was seconded to the Ministry of Supply as Aluminium Controller.

He later became a full-time member of the Industrial and Export Council of the Board of Trade, returning at first part-time, and subsequently full-time, to the service of the British Aluminium Co., Ltd., before the end of hostilities.

He is Deputy Chairman and Managing Director of the main companies of The British Aluminium group, and Chairman or Director of a number of subsidiary and associated companies. He is also interested in the Company's overseas activities, being a Director of the New Guinea Resources Prospecting Co., Ltd., and a Director and President of the Canadian British Aluminium Co., Ltd.

He sits on the Councils of the Aluminium Development Association, the Aluminium Industry Council, and the British Non-Ferrous Smelters' Association, and is a member of the Finance Committee of the British Standards Institution.

Dr. L. B. Hunt

(Member of Council)

Leslie Bernard Hunt was born in 1906 in Loughborough, and educated at Luton Grammar School and the Royal College of Science, London. Here he graduated B.Sc. and A.R.C.S., later obtaining the degrees of M.Sc. and Ph.D. for research work on the structure of electrodeposited metals.

From 1928 until 1934 he was employed as a metallurgist at Vauxhall Motors, Ltd., Luton, and during these years contributed a number of papers to the Institute of British Foundrymen, the Electrodepositors' Technical Society, and the Institution of Automobile Engineers.

At the beginning of 1935 he became Editor of *The Metal Industry*, a post he held until the end of 1937, when he was appointed Technical Manager of Mallory Metallurgical Products, Ltd., a newly formed subsidiary company of Johnson, Matthey and Co., Ltd., London, and P. R. Mallory and Co., Inc., of Indianapolis. This company was founded to manufacture a range of special high-conductivity copper alloys and also a series of powder-metallurgy products for use as electrical contacts and as resistance-welding electrode materials. Later it entered into the production of beryllium copper in the usual forms of strip, rod, wire, and tube.

In 1945 he was appointed Manager of the Industrial Division of Johnson, Matthey and Co., Ltd., and became concerned with the applications of silver and of the platinum metals in industry. He still holds this position.

In 1955 he was appointed a Director of Mallory Metallurgical Products, Ltd.

Lord Kirkwood of Bearsden

(Member of Council)

David Kirkwood was born in 1903 at Glasgow and was educated at Eastbank Academy and the Royal Technical College, Glasgow. He received his early metallurgical training with David Colville and Sons, Ltd. In 1928 he joined the National Smelting Co., Ltd., and he spent 1930 in the U.S.A. studying the commercial applications of high-purity zinc, with special reference to pressure die-casting. Closely associated with the pioneers of the die-casting industry, he has contributed in a large measure to its rapid development and growth in the United Kingdom. He was made a Director of the

National Smelting Co., Ltd., in 1950 and joined the Board of Imperial Smelting Corporation, Ltd., in 1957.

Lord Kirkwood was Deputy Controller, Non-Ferrous Metals Control, 1941–45, and Chairman of the Production Advisory Committee (Die-Casting) 1939–43. He is a Member of the Council of the Zinc Development Association and of the Zinc Alloy Die Casters Association.

He succeeded his Father, first Baron Kirkwood of Bearsden, in 1955.

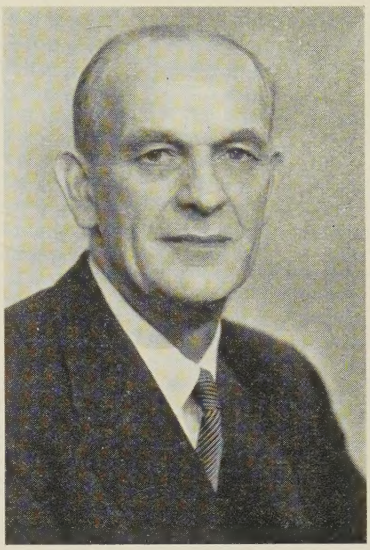
Mr. W. F. Randall

(Member of Council)

Walter Frederick Randall was educated at Rutlish School, Merton, and the Royal School of Mines, where he obtained the A.R.S.M. and the B.Sc. degree of London University.

In 1922 he joined the Telegraph Construction and Maintenance Co., Ltd., as Research Metallurgist. He is now Managing Director of the Metals Group of that Company, and Chairman or Managing Director of subsidiaries of the Group, which is engaged in the production of specialized alloys for the electrical and instrument-making industries.

Mr. Randall has been a member of the Institute since 1922. He is also a member of the Iron and Steel Institute, a fellow of

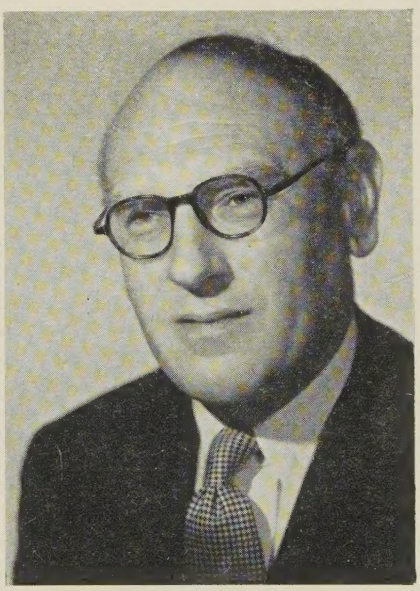


the Institution of Metallurgists, and a member of the Institution of Electrical Engineers.

Mr. F. W. Tomlinson

(Member of Council)

Frederick William Tomlinson was born at Worsley, Lancashire, in 1906, a son of the late Frederick Tomlinson of Manchester, who was a Member of Council of the Institute from 1921 until his death in 1937. He was educated at Clifton College and Emmanuel College, Cambridge, where he



graduated with a Natural Science Tripos in 1927. After leaving the University, he worked under the late Dr. W. Rosenhain for one year as Junior Assistant in the Metallurgical Department of the National Physical Laboratory, Teddington. He then joined the technical staff of the Broughton Copper Co., Ltd., Manchester, and remained there until 1933, when the Company was absorbed into the Metals Division of

Imperial Chemical Industries, Ltd. Mr. Tomlinson spent the next four years at Witton, his activities being divided between: (*a*) research administration and application, and (*b*) plant and process development of non-ferrous products. During his first ten years in industry, he specialized more particularly on the melting, casting, hot and cold working, and applications of copper and copper alloys, including practices in European countries and North America as well as in the United Kingdom.

In February 1938 Mr. Tomlinson was appointed General Manager of Pyrotenax, Ltd., Hebburn-on-Tyne, shortly after the formation of this Company, for the purpose of developing the patents, processes, and marketing rights of mineral-insulated copper-sheathed electric cables. In May 1938 he was appointed Managing Director of this Company, a position which he still holds, together with directorships of various subsidiary and associated companies overseas, including Executive Vice-President of Pyrotenax of Canada, Ltd., Director of Pyrotenax Australia Pty., Ltd., and Director of Giles and Elliott, Ltd., New Zealand.

Mr. Tomlinson has been a member of the Institute since 1928. He was elected to Associate Membership of the Institution of Electrical Engineers in 1944, and to full membership in January 1956.

LETTER TO THE EDITOR

The Two Regimes of Strain-Hardening

It is now generally conceded that the strain-hardening of ductile metals and alloys takes place by two distinctly different mechanisms. Cook and Richards [1–3] have discussed the matter in detail, and it has also been shown [4] that the strain-hardening curve can be expressed by two consecutive regimes of the exponential function, merging smoothly into each other. Junction occurs tangentially at a transition point which can be accurately located by equating the slopes of the two branches, but the two individual curves are normally so nearly coincident in the region of transition that the mechanisms of deformation which they represent can be considered to overlap, either or both together being operative over a considerable range of strain.

This approach is consistent with the views of Cook and Richards, and has the merit of being exceedingly simple and easy to handle mathematically. From the theoretical viewpoint, however, it is open to the criticism that, in all probability, both mechanisms are in fact operative throughout the strain-hardening process, the first dominating the earlier stages and the second controlling the later stages of deformation. The criticism can be met, and a composite equation devised, on the credible assumption that the second mechanism takes place only in those regions of the material which have already been affected by the first mechanism.

The present purpose is to explain the derivation of the composite equation. The result is necessarily more complicated than that obtained by the separate treatment of the individual regimes, and gives little if any better fit to the experimental data. It cannot, therefore, be recommended for practical use. On the other hand, it is of considerable theoretical importance to realize that the strain-hardening behaviour of metals can be explained quantitatively on the basis of two mechanisms occurring simultaneously instead of consecutively.

Derivation of the first-regime equation has been described elsewhere [5] but is briefly recapitulated here in a slightly modified form consistent with the present approach.

Let x be the proportion of a representative section which has undergone strain-hardening by the first mechanism. By common usage in connection with strain-hardening and annealing problems, the value of x can be measured by the proportionate change in the progressive yield stress, so that

$$x = \frac{Y_1 - Y_0}{Y_\infty - Y_0} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where Y_1 is the current value of the progressive yield stress, Y_0 is the *threshold stress*, or value of Y_1 before deformation, and Y_∞ is the *asymptotic stress*, or value of Y_1 attained after severe deformation.

The chance that a small increment of true (logarithmic) strain, $d\eta$, will increase the area affected by the first-regime mechanism is proportional to the area remaining unaffected, namely $(1 - x)$. Therefore

$$\frac{dx}{d\eta} = \frac{1 - x}{\eta_c} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where η_c is a constant of proportionality in strain units, called the *characteristic strain* for the regime in question.

Integration of equation (2) leads directly to the normal exponential function of strain-hardening, thus

$$C_1 - \ln (1 - x) = \eta / \eta_c$$

When $\eta = 0$, $x = 0$. Therefore $C_1 = 0$, and

$$x = \frac{Y_1 - Y_0}{Y_\infty - Y_0} = 1 - \exp (-\eta/\eta_c) \quad . \quad . \quad (3)$$

The form of this equation is shown graphically at B in Fig. 1. If curve A is the experimental strain-hardening curve of the material, embracing both regimes, then the contribution made by the second-regime mechanism can be obtained by subtracting the ordinates of curve B from those of curve A. The result is curve C. It rises slowly at first, where the influence of the second-regime mechanism is slight, then more rapidly, and later flattens out as the final asymptote is approached. Such behaviour is consistent with the assumption that the second-regime mechanism takes place in the regions which have already been affected by the first regime, as the following reasoning will show.

If y is the proportion of the representative section which has undergone strain-hardening by the second mechanism, then, for the second regime treated independently,

$$y = \frac{Y_2 - Y_0'}{Y_\infty' - Y_0'} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where Y_2, Y_0', and Y_∞' are respectively the progressive yield stress, threshold stress, and asymptotic stress for the second regime.

If the second regime can operate only in the regions which have already undergone strain-hardening by the first regime, then the chance that a small increment of strain will increase the area affected by the second regime is proportional to the area which has been affected by the first regime, but which has not yet been affected by the second regime. This proportion of the whole representative section is clearly $x(1 - y)$, so that, for the second regime,

$$\frac{dy}{d\eta} = \frac{x(1 - y)}{\eta_c'} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where η_c' is the characteristic strain for the second regime. Substituting for x from equation (3), and integrating

$$C_2 - \ln(1-\gamma) = \frac{\eta + \eta_c \exp(-\eta/\eta_c)}{\eta_c'}$$

When $\eta = 0$, $\gamma = 0$. Therefore $C_2 = \eta_c/\eta_c'$, and, after suitable manipulation,

$$\gamma = \frac{Y_2 - Y_0'}{Y_\infty' - Y_0'} = 1 - \exp\left[-\frac{1}{\eta_c'}\left(\eta - \eta_c\left\{1 - \exp\left(-\frac{\eta}{\eta_c}\right)\right\}\right)\right] \quad (6)$$

Equations (3) and (6) can now be combined to find the full value, Y, of the progressive yield stress, for it is evident that this is the sum of the contributions from the two regimes, i.e. $Y = Y_1 + Y_2$. The result is

$$Y = (Y_\infty + Y_\infty') - (Y_\infty - Y_0)\exp(-\eta/\eta_c) - (Y_\infty' - Y_0')\exp\left[-\frac{1}{\eta_c'}\left(\eta - \eta_c\left\{1 - \exp\left(-\frac{\eta}{\eta_c}\right)\right\}\right)\right] \quad (7)$$

The experimental data in Fig. 1 have been taken directly from Table I, headed "Typical Results", of a paper by Ford.[6] They represent tensile tests on high-conductivity copper strip cold rolled to various reductions. The tensile stress/strain curves are set at their appropriate positions in respect of rolling strain, and their extremities define the strain-hardening curve of the material. Coiling and slitting operations after the final anneal had slightly strain-hardened the metal, so that its threshold stress was above that of fully annealed copper.

The unbroken curve at A has been computed from equation (7), using the following constants:

	1st Regime	2nd Regime
Threshold stress, tons/in.^{2}	7·2	0·1
Asymptotic stress, tons/in.^{2}	19·7	8·9
Characteristic strain, logarithmic	0·12	0·73

Curve B represents the first regime in accordance with equation (3) and curve C the second regime calculated from equation (6), each with the appropriate constants given above.

The broken curve at A is that obtained by the normal process of analysis, based on two independent regimes. The constants are:

	1st Regime	2nd Regime
Threshold stress, tons/in.^{2}	7·3	14·4
Asymptotic stress, tons/in.^{2}	22·2	28·9
Characteristic strain, logarithmic	0·14	0·50

The branches make tangential junction at a transition point defined by:

Transition stress	20·0 tons/in.^{2}
Transition strain	0·267 logarithmic

The critical point, corresponding to the maximum load in tension, can readily be obtained by this method of analysis, though not from the composite function. It is defined by:

Critical stress	19·5 tons/in.^{2}
Critical strain	0·238 logarithmic
Uniform extension	26·9%
Tensile strength	15·4 tons/in.^{2}

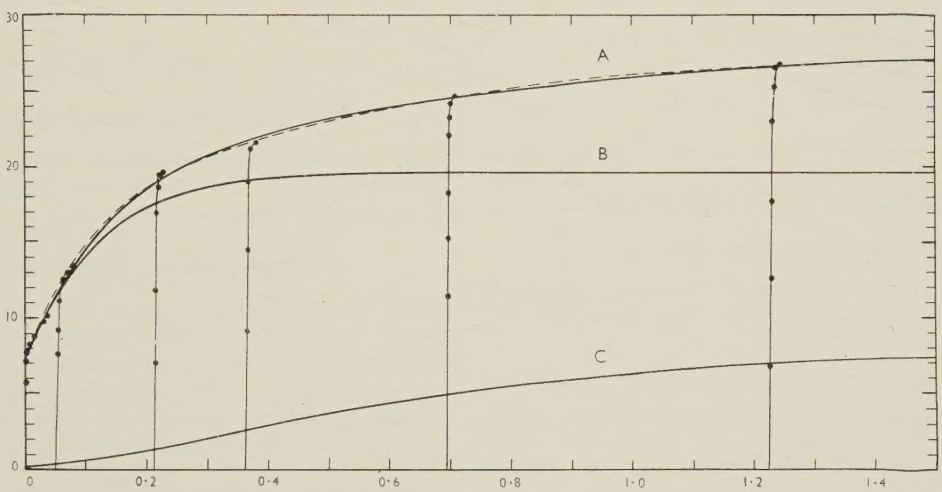


FIG. 1.—Strain-hardening curve for copper (*Ford* [6]).
Curves A, B, and C: composite equation. Broken curve: two independent regimes.

Equation (7) represents a strain-hardening curve which is fully consistent with those of normal experience, and it seems likely that real metals do, in fact, behave essentially in accordance with the assumptions on which it is based. On the other hand, it is far more complicated and tedious to handle arithmetically than the separate treatment of two consecutive regimes with tangential junction between them. Moreover, no satisfactory method, other than trial and error, has been found for determining the constants from an experimental curve, because each regime masks the other except at very small or very large deformations. In these regions the normal techniques [4] can be used, with caution, to obtain tentative values, but the subsequent processes of adjustment necessary to secure a proper fit are laborious. In contrast, a good fit can almost invariably be found quite quickly on the basis of two consecutive regimes. Other objections to the composite equation are that such important parameters as the critical point (true tensile strength) and ordinary tensile strength cannot readily be deduced from it, and that it is too clumsy for convenient application to industrial cold-working processes.

The slightly high tensile strength and low uniform extension are attributable to the cold work imposed by coiling and slitting already mentioned. The threshold stress for annealed high-conductivity copper is normally about 3 tons/in.^{2}. Accepting this value, the latent strain imposed by coiling and slitting can be calculated to be 0·036, equivalent to 3·5% reduction of sectional area, or 3·6% extension. Deductions such as this would be much less easy to make from the composite function.

The diagram shows that both methods of approach, with simultaneous or successive regimes respectively, give strain-hardening curves in good accord with experiment. The composite function is perhaps theoretically preferable, and its implications would seem to be important, but the use of consecutive and independent regimes has many practical advantages.

E. VOCE

Copper Development Association,
London, W.1.

REFERENCES

1. M. Cook and T. Ll. Richards, *J. Inst. Metals*, 1940, **66**, 1.
2. M. Cook and T. Ll. Richards, *ibid.*, 1943, **69**, 351.
3. M. Cook and T. Ll. Richards, *ibid.*, 1950–51, **78**, 463.
4. E. Voce, *Metallurgia*, 1955, **51**, 219.
5. E. Voce, *Engineer*, 1953, **195**, 23.
6. H. Ford, *Proc. Inst. Mech. Eng.*, 1948, **159**, 115.

JOINT ACTIVITIES

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee announced recently the award of a Fellowship for 1957 to the following applicants:

MR. E. J. WILLIAMS (John Summers and Sons, Ltd.) to study the research and production techniques, quality control and metallurgy of high-quality low-carbon strip steel in the United Kingdom, the Continent, and the United States.

MR. R. J. D. ACHESON (Mufulira Copper Mines, Ltd.) to study the extraction and refining processes for copper and allied metals, with particular reference to economic aspects.

The Mond Nickel Fellowships Committee now invites applications for the award of Mond Nickel Fellowships for the year 1958. Awards will be made to selected applicants of British nationality educated to University degree or similar standard, though not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments; they will normally take the form of travelling Fellowships. Awards for training at Universities will be made only in exceptional circumstances. There are no age limits, though awards will seldom be given to persons over 35 years of age. Each Fellowship will occupy one full working year. The Committee hope to award up to five Fellowships each year of an approximate value of £900–£1200 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects:

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons qualified in Sciences other than Metallurgy may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications, and previous career. Full particulars and forms of application can be obtained from: The Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1.

Completed application forms will be required to reach the Secretary of the Committee not later than 1 June 1958.

OTHER NEWS

Third World Metallurgical Congress

It is announced by the American Society for Metals that they will hold a Third World Metallurgical Congress in Chicago in November 1962.

The Institute of Physics

The Non-Destructive Testing Group of the Institute of Physics is to hold a joint conference with the Société Française de Métallurgie in Paris on 16–20 June 1958. The theme of the conference will be: "The utilization of physical properties for studying the relationships between the constitution structure, and service behaviour of metals".

International Mineral-Processing Congress April, 1960

The Institution of Mining and Metallurgy will hold an International Congress on Mineral Processing in London from 6 to 9 April 1960. It is proposed that the papers to be discussed shall cover fundamental and applied research and development in the fields of mineral dressing, chemical processing, roasting, cyanidation, leaching, and solvent extraction, but not smelting.

Enquiries should be addressed to: The Secretary, The Institution of Mining and Metallurgy, 44 Portland Place, London, W.1.

Symposium on "Instrumentation and Computation in Process Development and Plant Design"

The Institution of Chemical Engineers, in conjunction with the Society of Instrument Technology and the British Computers' Society, proposes to hold a symposium on "Instrumentation and Computation in Process Development and Plant Design". The meeting will take place in London in 1959, probably on 11–13 May. Fuller details will be published later.